Adjusting Tree Volume, Decay, and Waste Estimates in British Columbia

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Executive Summary

This paper summarizes two methods developed by the BC Ministry of Forests Resources Inventory Branch to adjust tree volume (taper), decay, and waste estimates:

1. Net Volume Adjustment Factor (NVAF) Sampling – for application with the Vegetation Resources Inventory (VRI) where stem analysis of trees in VRI plots is used to adjust the cruiser-called net volume.
2. Flewelling's method – to adjust taper, decay, and waste equations from stem analysis data obtained from any source – including NVAF sampling.

NVAF Sampling – uses destructively sampled trees from an unbiased sample from VRI plots to adjust tree net volumes for differences in taper equations, errors in net factor rules, hidden decay in trees with no loss indicators or no visible decay, and hidden loss indicators (the method does not account for waste). Trees are randomly selected from auxiliary plots in VRI sample clusters, felled, and measured for actual taper and decay. The NVAF is applied to all species, although the methods can be applied to one species at a time.

Flewelling's Method – adjusts taper, decay, and waste equations using stem analysis data obtained from any source. Adjustments can be developed for individual or groups of species. Flewelling's taper-adjustment method allows for direct log-size assortment estimates that are compatible with adjusted total volume; the NVAF does not. Neither method offers direct means of allocating waste and decay to log-size assortment tables, although approximate methods could be developed.

The NVAF and the Flewelling approaches to adjusting volume estimates were developed simultaneously to address related needs. The NVAF was developed to adjust taper and decay estimates, and is an integral part of the VRI. The Flewelling method was developed to adjust:

- Regional taper equations (which can be used in VRI and valuation cruising).
- Decay and waste estimates (used in valuation cruising where NVAF is not used).

The two methods are statistically sound and complimentary. We do not propose any new modifications to either method.

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1. INTRODUCTION

1.1 OBJECTIVES

This paper summarizes the two methods developed by the BC Ministry of Forests (MOF) Resources Inventory Branch to adjust tree volume, decay, and waste estimates. These methods were developed based on destructive tree sampling data (using MOF procedures[1]) from various projects, and as part of the Vegetation Resources Inventory (VRI).

1.2 TERMS OF REFERENCE

The MOF Growth and Yield Monitoring Task Force (GYMTF) made recommendations on developing growth and yield monitoring protocols which were accepted by the Forest Productivity Council (FPC). These protocols are expected to cover growth and yield, decay and waste, stand treatments, forest health, site productivity, and the Canadian Council of Forest Ministers (CCFM) Criteria and Indicators (C&I) of sustainable forest management.

This summary was completed under contract to the MOF Resources Inventory Branch by our team including Ian Cameron, *MF, RPF,* Eleanor McWilliams, *MSc, RPF,* A.Y. Omule, *PhD, RPF,* Guillaume Thérien, *PhD,* and Jim Thrower, *PhD, RPF.*

1.3 BACKGROUND

Two methods developed in BC to adjust estimates of tree volume (taper), decay, and waste are:

1. **Net Volume Adjustment Factor (NVAF) Sampling** – destructive sampling done in conjunction with the VRI to adjust estimates of tree net volume for difference in taper equations, cruiser-called net factors, and other factors that affect individual tree estimates.
2. **Flewelling's Method** – adjusts taper, decay, and waste equations using stem analysis data obtained from any source using MOF methods, including VRI sampling studies.

NVAF Sampling – corrects for possible taper equation error, net factor rule error, decay (close utilization wood volume lost to incipient, advanced, or final stages of decay) in trees with no loss indicators or visible decay, and hidden loss indicators. The method does not account for waste (non-recoverable volume in trees or logs greater than 50% defective). NVAF sampling develops one factor for all species in an inventory unit, but could also be used for individual species. The inventory unit may be an entire Forest District (provincial VRI) or a sub-unit in a District (e.g., management inventory).

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[1] Methods on cruising and destructive sampling are available in the MOF Resources Inventory Branch document *Net Volume Adjustment Factor Sampling Standards and Procedures*, Draft No. 2, Version 1, Sept. 14, 1998 (Contact Will Smith).

The taper equations used in BC predict inside bark diameter at a given height as a function of total height, diameter at breast height (DBH), Biogeoclimatic Ecological Classification (BEC) zone, and species. Tree volume is estimated through numerical integration of the taper equations. Decay equations reduce gross to net volume (whole-stem volume less stump and top) by a percentage as a function of DBH, species, risk group, and BEC zone. Waste equations estimate reductions as a percentage, function of the same four attributes.

Flewelling's method[2] – adjusts taper, decay, and waste equations using stem-analysis data with known selection probabilities. These data can be obtained through sampling for this purpose or from other projects. This method adjusts by species but can be applied across species. Sample sizes may differ for all-species and by-species. These methods were developed using volume and decay studies in the Queen Charlotte Islands, the ICH non-wetbelt areas in the Golden TSA, and the ICH wetbelt areas in the Golden, Kamloops, Okanagan, Revelstoke, and Robson TSAs.

2. THE NVAF METHOD

2.1 OBJECTIVE

The NVAF method provides an unbiased estimate of net merchantable volume for an inventory unit based on stem analysis of trees from auxiliary plots in the VRI plot clusters. The VRI cruiser-called net volume estimates may differ from stem analysis because of bias in taper equations, errors in net factor rules, hidden decay in trees with no visible loss indicators or decay, and hidden loss indicators. The VRI cruiser-called net volumes are based on estimation and measurement rules for trees with visible decay. The inventory unit may be an entire Forest District, TSA, TFL, or sub-unit.

2.2 SAMPLING

Destructive sampling for NVAF is conducted after completion of the VRI Ground Sampling. Sample trees are selected from the list of trees in the auxiliary plots in the VRI plots clusters. Trees are then selected from this list with known weights (Section 2.3.1). The sample trees are then felled to measure taper and decay.

The NVAF process can be implemented as follows:

Office Procedures

1. Define the inventory unit (Forest District, TSA, TFL, or sub-unit).

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[2] Flewelling, J. 1998. *Volume and decay monitoring analysis: The QCI methodology.* Available from MOF Resources Inventory Branch, Victoria, BC. September 15, 1998 (contact: Ken Richardson).

2. Systematically select 15 sample points from the VRI ground samples (vegetated treed; select two vegetated non-treed samples if applicable).
3. Tally all trees (dead and live) in all auxiliary plots.
4. Group data into live and dead trees with diameters ≥ 12.5 cm.[3]
5. Randomly select at least 30 live trees and 10 dead trees.[4]

Field Procedures

6. Destructively sample selected trees for volume and decay (substitution should be avoided).
7. Measure volume and decay using MOF procedures.[5]

2.3 ANALYSIS

2.3.1 Assembling the Data

The Auxiliary Plot Cruise (APC) data are compiled to estimate volume/tree and volume/ha. Individual tree volumes are based on diameter and height measurements from destructive sampling. Gross and merchantable tree volumes are estimated using the BEC-based version of the MOF (Kozak's) taper equations. Net merchantable tree volume is calculated using the cruiser-called net factor. The calculation of individual tree volumes adheres to the VRI tree compilation standard.

The weight of each sample tree is calculated to consider the selection probability and corresponding representation in the population. Each tree weight must consider:

1. Sample Point Selection – the probability of selecting a sample point from all points in the VRI.
2. Sample Tree Volume – accounts for the proportion of sample gross volume per hectare represented by the tree.
3. Sample Tree Stratum – the probability of selecting an individual tree from the list of trees in the stratum.
4. The volume and decay sample tree data are compiled using the MOF Resources Inventory Branch Volume and Decay tree compiler. This compiler produces standard compiled tree volumes by gross and merchantable, decay, and waste volumes, based on MOF Resources Inventory Branch Volume and Decay Program standards.

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[3] This approach assumes that adjusting net volume of trees below 12.5 cm is not important.

[4] Sample size and stratification criteria are based on variability of the NVAF in the Boston Bar area. These criteria may be changed as we accumulate experience with these methods.

[5] Methods on cruising and destructive sampling are available in the MOF Resources Inventory Branch document *Net Volume Adjustment Factor Sampling Standards and Procedures*, Draft No. 2, Version 1, Sept. 14, 1998 (Contact Will Smith).

2.3.2 Calculating the NVAF

Live and dead tree NVAF coefficients are calculated for all species in the inventory unit. The NVAF is the average ratio of the actual net merchantable volume to the cruiser-called net merchantable volume:

$$NVAF = \frac{w_i y_i}{w_i x_i} = \frac{\dot{y}_i}{\dot{x}_i}$$

where

w_i = the tree sampling weight
y_i = actual net merchantable volume based on destructive sampling
x_i = the cruiser-called net merchantable volume
and the summation is over all sample trees, n

The standard error of the NVAF (*SE(NVAF)*) is estimated as:

$$SE(NVAF) = \sqrt{\frac{\left[\left(\dot{y}_i - \bar{\dot{y}}\right) - NVAF\left(\left(\dot{x}_i - \bar{\dot{x}}\right)\right)\right]^2}{\left[\bar{\dot{x}}\right]^2 \times n \times (n-1)}}$$

where

$$\bar{\dot{x}} = \frac{w_i x_i}{n} \quad \text{and} \quad \bar{\dot{y}} = \frac{w_i y_i}{n}$$

Confidence intervals (1-α) can be computed as:

$$NVAF \pm t_{\frac{\alpha}{2}, n-2} SE(NVAF)$$

Future theoretical sample size, n_0, can also be approximated as:

$$n_0 = \frac{t^2 [CV(NVAF)]^2}{E^2}$$

where

$$CV(NVAF) = [SE(NVAF)100\sqrt{n}] / NVAF$$

E = the desired precision (e.g., ±10% at 95% probability)

2.3.3 Adjusting Net Volume

The NVAF is applied during compilation of the VRI net volumes. The coefficient is multiplied by the cruiser's initial net-volume estimate for each sample tree in the inventory unit.

2.4 MODIFICATIONS

2.4.1 Localize NVAF to Strata

The MOF localizes NVAF estimates by creating separate populations (sub-units) in the inventory unit. A sub-unit could be a specific geographic area (e.g., operable land-base) or land type (e.g., ICH wetbelt forest types). Sampling intensity and error can then be controlled in the sub-unit by adding samples or stratifying the sub-unit (e.g., by species). The field procedures and analyses would be similar to those outlined in Sections 2.2 and 2.3.

2.4.2 Adjusting Taper, Decay and Waste Equations

The MOF has recommended a passive approach (Section 3.2) to collect data to adjust taper, decay, and waste equations, thus it is not necessary to modify the NVAF sampling approach.
However, proper documentation of the NVAF sample selection probabilities and weights is important.
Special requests to adjust these equations for specific areas:

- Should be treated as sub-units (Section 2.4.1);
- Require preparation of a sampling plan; and
- Follow the NVAF sampling approach and the Flewelling analysis approach (Section 3).

2.5 IMPLEMENTATION

The NVAF sampling is an integral part of the VRI ground sampling, which may cover the entire landbase in a District or sub-unit within a District. The NVAF sampling should accompany each timber-emphasis sub-unit management inventory to provide precise estimates of sub-unit net volume. If sub-unit NVAFs are not available, the District-wide NVAFs can be used. However, the resulting net volume estimates would not be as precise as sub-unit adjustments.

The NVAF sampling for a District can be coupled with ground sampling (following VRI plans) or can be done independently. The NVAFs for each District (or group of Districts) would be applicable to any sub-unit within the District. The NVAF coefficients can be audited over time by systematically selecting additional sample locations from the original list of VRI samples.

2.6 DISCUSSION

An operational implementation of NVAF sampling has not been completed in BC. There are several components of the NVAF process that we suggest be addressed by the MOF. These components include:

- The effect of destructive sampling in the VRI plots, including recompilations and possible linkage with growth and yield monitoring programs.
- How to combine the VRI NVAF sample with data collected in previous special studies (e.g., data used to develop the Flewelling method) in an inventory unit.

3. FLEWELLING'S METHOD

3.1 OBJECTIVES

The objectives of Flewelling's method for adjusting taper, decay, and waste equations are to provide better gross and net volume estimates for localized strata, and to provide compatible estimates of those volumes at the tree level, and possibly for individual logs.

3.2 SAMPLING

Flewelling's method uses data from any source (i.e., passive data collection). This strategy involves accumulating destructive sampling data with known selection probabilities and populations as they become available from other projects (e.g., VRI NVAF sampling). These data are typically stratified by species, risk group, BEC, and height (for taper); however, it may be difficult to compute probabilities and weights from some sources.

3.3 ANALYSIS

3.3.1 Assembling the Data

The data of interest are for volume and decay, where each observation is one destructively sampled tree. Key variables are actual volumes, volume predicted from the taper equations (based on the most careful determinations of DBH and height), and sample weights. Predicted volumes should be calculated using the taper equations and a moderately tight integration rule.[6] Actual and predicted volumes should be calculated using similar rules to prevent possible method bias. Sampling weights are as discussed in section 2 for gross close utilization volume. In general, each species is addressed separately. Species misidentification should be considered where common.

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[6] Flewelling, J. 1998. *Volume and decay monitoring analysis: The QCI methodology.* Available from MOF Resources Inventory Branch, Victoria, BC. September 15, 1998 (contact: Ken Richardson).

3.3.2 Calculating the Adjustment Ratios

The overall adjustment ratio is RV = [Gross actual volume]/[Whole stem estimated volume]:

$$RV = \frac{w_i y_i}{w_i x_i} = \frac{y_i}{x_i}$$

where

w_i = the tree weight

y_i = actual volume

x_i = the predicted net volume (whole-stem volume)

This formula is identical to the NVAF formula (for gross close utilization volume) as $w_i = w'/x_i$ This approach is often called the "ratio of means."

The standard error of the weighted ratio, *SE(RV)*, is:

$$SE(RV) = \sqrt{\frac{\left[\left(y_i' - \bar{y}'\right) - RV\left(\left(x_i' - \bar{x}'\right)\right)\right]^2}{\left[\bar{x}'\right]^2 \times n \times (n-1)}}$$

where

$$\bar{x}' = \frac{w_i x_i}{n} \text{ and } \bar{y}' = \frac{w_i y_i}{n}$$

Confidence intervals (1-α) can be estimated as:

$$RV \pm t_{\frac{\alpha}{2}, n-2} SE(RV)$$

Ratios for decay (RD) and waste (RW) are calculated as:

RD = [Actual Decay Volume/ Estimated Decay Volume]

RW = [Actual Waste Volume/ Estimated Waste Volume]

3.3.3 Adjusting Taper, Decay, and Waste Equations

The adjustment process may involve:

- Refitting or reformulating equations if the observed bias is large (10% or more). Adjustment factors are still required after the taper equation is refit.
- Applying a simple adjustment factor to existing equation coefficients.

One method to adjust taper-based estimates of tree volume is to multiply the taper-predicted volume by the appropriate ratio. An alternative method is to multiply each predicted diameter by the square root of the ratio RV.[7] The second method distributes volume adjustment to the trees, and ensures log-size assortment tables, if calculated, are compatible with the volume estimates. However, this method should not be applied to make large adjustments to volume. Adjustments that exceed 10% indicate a serious problem with taper equations that should be addressed by refitting or reformulating the equation.

Adjusting decay and waste equations involves:

- Modifying taper equations to estimate volume, decay, and waste.
- Modifying the decay and waste equations.
- Applying the decay adjustment ratios to all risk groups.

The adjustment of decay and waste estimates involves several steps applied to each sample tree:

1. Adjust the taper equation using the ratio RV. To obtain volume after a taper adjustment, multiply all predicted diameters from the taper equation by the square root of RV and calculate adjusted whole-stem volume through integration.
2. Adjust the decay estimates by multiplying the estimated decay amount by RD. To obtain net volume (adjusted for taper and decay) subtract the adjusted decay volume from the adjusted whole-stem volume in 1.
3. Adjust the waste estimates by multiplying the estimated waste amount by RW. To obtain net volume (adjusted for taper, decay, and waste) subtract the adjusted waste volume from the net volume (adjusted for taper and decay) in 2.

This adjustment process was applied in the Queen Charlotte Islands TSA. Details are provided in the MOF Resources Inventory Branch report *Queen Charlotte Islands TSA Timber Supply Analysis FIP File Adjustment Process (February 1999).*

3.4 IMPLEMENTATION

The MOF Resources Inventory Branch can use this adjustment process on a routine basis (as data accumulate) to adjust Regional taper equations for use in VRI and valuation cruising, and decay and

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[7] Gross volume is woody tree volume and does not include volume of broken tops. Hence, the adjusted volume to calculate this ratio will be an unbiased estimate of the total woody volume in the forest. However, if the cruise process and compilers make specific adjustments for broken tops (they do not now), there would be double accounting of broken tops. If the cruise procedures were changed to specifically account for broken tops, the correct RV computation would use total volume (including broken tops) in the numerator.

waste estimates for valuation cruising where NVAF is not used. The population of interest can be a geographic area, BEC zone, tree species, or group of species.

The adjustment process is implemented as follows:

1. Define the population of interest.
2. Select the taper, decay, and waste equations to be adjusted.
3. Collate the destructive sampling data.
4. Compute volume sample-based adjustment ratios from the felled sample tree data.
5. Apply the volume ratio to the taper, decay, and waste equation estimates.

4. CONCLUSION

The NVAF and the Flewelling approaches to adjusting volume estimates were developed simultaneously to address related needs. The NVAF was developed to adjust taper and decay estimates, and is an integral part of the VRI. The Flewelling method was developed to adjust:

- Regional taper equations (which can be used in VRI and valuation cruising).
- Decay and waste estimates (used in valuation cruising where NVAF is not used).

The two methods are statistically sound and complimentary. We do not propose any new modifications to either method.